

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>Basics</b>	<b>4</b>
2.1	O Notation . . . . .	5
2.2	Basic Data Structures and Algorithms . . . . .	5
2.2.1	Meshes . . . . .	5
2.2.2	Textures . . . . .	6
2.2.3	Scene Graphs . . . . .	6
2.3	Botany . . . . .	7
<b>3</b>	<b>Related Work</b>	<b>9</b>
3.1	Visual Dataflow Pipelines . . . . .	9
3.2	Procedural Modeling . . . . .	11
3.2.1	Properties and Use Cases of Procedural Models . . . . .	11
3.2.2	Extrusion . . . . .	12
3.2.3	Generative Modeling . . . . .	13
3.2.4	Programming and Scripting for Procedural Modeling . . . . .	14
3.2.5	Fractals . . . . .	14
3.2.6	Particle Systems . . . . .	15
3.2.7	L-Systems . . . . .	15
3.2.8	Procedural Modeling of Trees . . . . .	17
3.2.9	Xfrog . . . . .	19
3.2.10	Procedural Modeling of Cities . . . . .	20
3.2.11	Procedural Modeling of Terrain . . . . .	24
3.2.12	Erosion Simulation . . . . .	27
3.2.13	Procedural Textures . . . . .	28
3.3	Terrain Rendering and Level of Detail . . . . .	29
3.4	Further Modeling and Editing Approaches . . . . .	30
3.4.1	Terrain Editing . . . . .	30
3.4.2	Sketch-Based Modeling . . . . .	30
3.4.3	Image-Based Modeling . . . . .	31
3.4.4	Modeling by Example . . . . .	31
3.5	3D Modeling in Practice . . . . .	33
3.5.1	3D Modeling Suites . . . . .	33
3.5.2	Developing Plugins . . . . .	34
3.5.3	Procedural Modeling in Computer Games . . . . .	34

<b>4</b>	<b>A New Visual Paradigm for Procedural Modeling</b>	<b>37</b>
4.1	Introducing Model Graphs . . . . .	40
4.1.1	Language Definition . . . . .	40
4.1.2	Basic Node Types . . . . .	44
4.1.3	Scene Graph Management . . . . .	46
4.2	Introductory Example . . . . .	51
4.3	Additional Language Features . . . . .	55
4.3.1	Control Operators . . . . .	55
4.3.2	Variable Types . . . . .	56
4.3.3	Records . . . . .	56
4.3.4	Updating variables . . . . .	57
4.3.5	Calling Other Model Graphs and Recursion . . . . .	58
4.3.6	Parallelization . . . . .	61
4.3.7	Texture Generators . . . . .	62
4.3.8	Geometry Creation . . . . .	64
4.3.9	Animation . . . . .	67
4.4	User Interface . . . . .	68
4.4.1	Object Picking . . . . .	68
4.4.2	Control Points . . . . .	69
4.5	Implementation . . . . .	70
4.5.1	General Optimizations . . . . .	70
4.5.2	Rendering Optimizations . . . . .	71
4.5.3	File Formats . . . . .	72
4.6	Examples . . . . .	73
4.6.1	Creating Plants . . . . .	73
4.6.2	Creating Buildings . . . . .	74
4.6.3	Creating Terrain . . . . .	76
4.6.4	Smoothing Terrain . . . . .	78
4.6.5	Midpoint Displacement . . . . .	79
4.6.6	Erosion Simulation . . . . .	80
4.6.7	Fractals . . . . .	83
4.6.8	Animation . . . . .	85
4.6.9	Model Graphs that Emulate Turing Machines . . . . .	86
4.6.10	Putting It All Together . . . . .	87
4.7	Discussion . . . . .	88
4.8	Conclusion . . . . .	90

<b>5</b>	<b>Increasing Usability of Procedural Modeling with an Editing Approach</b>	<b>91</b>
5.1	Using 1-2-tree . . . . .	93
5.1.1	Selection . . . . .	93
5.1.2	Viewport Tools . . . . .	94
5.1.3	Parameters . . . . .	94
5.2	Implementation . . . . .	96
5.2.1	Selection in the Viewport . . . . .	96
5.2.2	Parameter Updates . . . . .	96
5.2.3	Viewport Tools . . . . .	97
5.2.4	Geometry Creation and Rendering . . . . .	98
5.2.5	Persistence . . . . .	98
5.2.6	File Formats . . . . .	99
5.3	Results . . . . .	100
5.4	Discussion . . . . .	103
5.5	Conclusion . . . . .	105
<b>6</b>	<b>Editing 3D models using templates</b>	<b>106</b>
6.1	Design Considerations . . . . .	106
6.2	Implementation . . . . .	108
6.2.1	User Interface . . . . .	108
6.2.2	Data Exchange . . . . .	109
6.3	Results . . . . .	111
6.3.1	Architecture . . . . .	111
6.3.2	Terrain . . . . .	111
6.3.3	Trees and plants . . . . .	111
6.4	Discussion . . . . .	113
<b>7</b>	<b>Procedural Terrain with River Networks</b>	<b>114</b>
7.1	Analysis . . . . .	115
7.2	Overview . . . . .	117
7.3	Planet Creation . . . . .	118
7.3.1	Create Base Shape . . . . .	119
7.3.2	Define Continents . . . . .	120
7.3.3	Produce Initial River Networks . . . . .	120
7.3.4	Assign Altitudes . . . . .	122
7.3.5	Compute Water Levels . . . . .	123
7.3.6	Assign Vertex Colors . . . . .	123

7.4	Adaptive Level of Detail . . . . .	125
7.4.1	Refinement . . . . .	125
7.4.2	Reversing and Reapplying Refinements . . . . .	127
7.4.3	Reproducibility . . . . .	128
7.4.4	Create Geometry for Lakes and Rivers . . . . .	129
7.5	CPU Implementation . . . . .	131
7.6	GPU Implementation . . . . .	132
7.7	Discussion . . . . .	133
<b>8</b>	<b>Systems Comparison</b>	<b>135</b>
<b>9</b>	<b>Conclusion</b>	<b>139</b>
<b>10</b>	<b>Future Work</b>	<b>141</b>
10.1	Terrain Modeling . . . . .	141
10.2	Crust Movements . . . . .	141
10.3	User-Controlled Modeling of Planets . . . . .	141
10.4	Transportation Networks . . . . .	142
10.5	Placing Lakes and Endorheic Basins . . . . .	144
10.6	Compiled model graphs . . . . .	144
10.7	Parallel Execution of Model Graphs in Case of Several Root Nodes . .	145
10.8	Templates and Scene Graph Hierarchies . . . . .	145
10.9	Further Improvements to Templates . . . . .	145
<b>A</b>	<b>Control Operators in plab</b>	<b>147</b>
<b>B</b>	<b>Operators in plab</b>	<b>149</b>
<b>C</b>	<b>Texture Generators</b>	<b>155</b>
<b>D</b>	<b>Components</b>	<b>157</b>
<b>E</b>	<b>Functions</b>	<b>161</b>
<b>F</b>	<b>Hints for Programming in plab</b>	<b>162</b>
<b>G</b>	<b>Parameters for Terrain Modeling</b>	<b>163</b>
<b>H</b>	<b>Modeling Software</b>	<b>164</b>